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14. ABSTRACT
USPL Laboratory Update: Reconfigured and now achieving 6.5 TW. Propagate laser to 2k & 5k site has begun. Progress on Nonlinear Propagation: Media with second and third harmonic generation present mathematical complexities in previous results that have been now simplified. Work on competing nonlinearities and propagation: We have deviated from Farnum/Kutz work to include a more uniform definition for dispersion. We have kept the 2^{nd} order derivatives in time for a finer look at dispersion. Under SEVA and other assumptions or equations reduce to a form previously published but little computational work on them is available. Computational efforts underway: New results from a RK5 & FFT methodology and 6-pt Crank-Nicholson for our simplest form. We will move to solve the more complicated forms numerically in the future. Couple this work with plasma work by out group.

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Prescribed by ANSI Std. 239.18

DoD Center of Excellence to Support Theory and Experiments on Filamentation Topics for DDR&E's Recent MURI Initiatives

DEPS USL Workshop
14 June 2012

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Air Force Research Laboratory
Advanced Electric Laser Branch
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Sandia National Laboratories

Kirtland AFB, NM

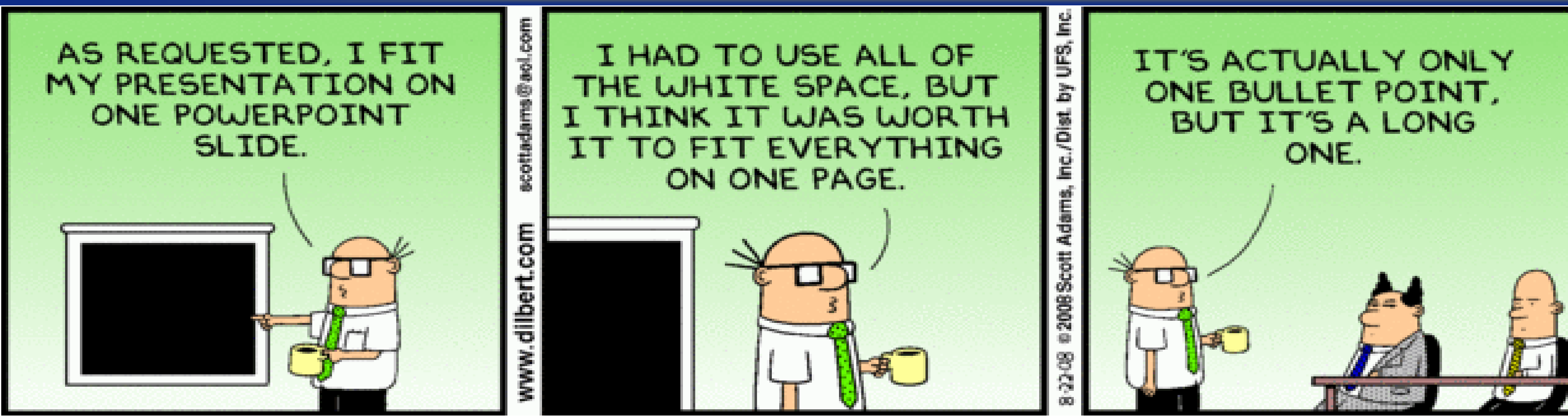
Sandia National Laboratories

Dr. Arje Nachman & Dr. Enrique Parra

Air Force Office of Scientific Research

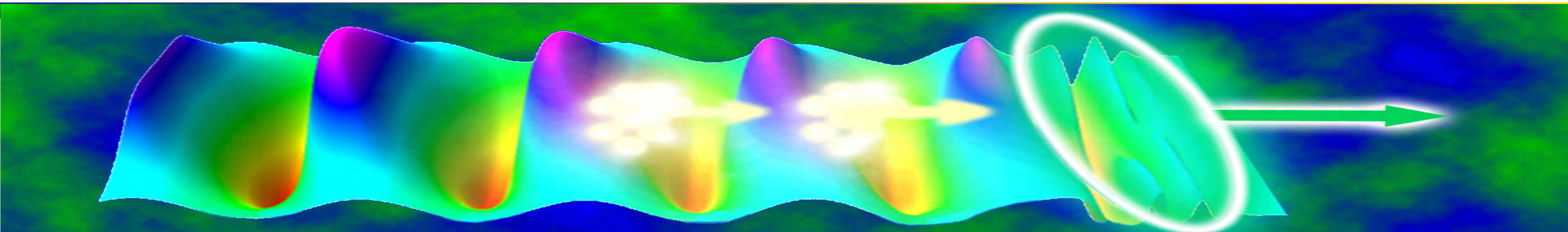
Ballston, VA

Overview



- **USPL Laboratory design, building, and updates at AFRL/RD**
- **Progress on Nonlinear Propagation**
  - **AFOSR MURI Collaboration**
- **Theoretical and Computational efforts underway**
  - **New results from a RK5 & FFT methodology and 6-pt Crank-Nicolson scheme**
- **Summary and Conclusions**

Unique Characteristics To Potentially Exploit In USPL



A laser pulse traveling through a plasma, indicated by the ellipse at right, accelerates bunches of free electrons (center) in its wake

P. Preuss, BELLA: The Next Stage in Laser Wakefield Acceleration, Lawrence Berkley National Laboratory News Center, April 15, 2008.
http://newscenter.lbl.gov/feature-stories/2008/04/15/bella-the-next-stage-in-laser-wakefield-acceleration/

- **USPL Characteristics: Very short pulse durations (notionally 10ps-10fs)**
    - **High peak intensity and electric fields and broad spectral bandwidth**
  - **Effects**
    - **Self induced nonlinear optics**
    - **Mulitphoton ionization (filamentation) plasma creation**
    - **Material modification / damage**
    - **Multi-spectral generation (RF, THz, EUV, x-rays, e^+e^- pairs)**
    - **Electron acceleration**

Importance of Laser Filaments

Operational uses

- Filamentation process is the leading candidate to localize electromagnetic fields for sensing, imaging, and non-imperceptible communications (Low probability of intercept communication)
- Design new models for non-kinetic attack which offer covert and limited or no collateral damage
- New knowledge is required to address the problem of efficient and effective communication through plasma shields which isolate the space shuttle on atmosphere re-entry and clearly isolate the United States Air Force super-sonic vehicle from ground communications

Capability Sought

- That fs induced filaments may act as an effective waveguide in both the longitudinal and transverse directions
- If it is plausible to confine external EM fields, both CW and pulsed sources, within a small extended filament that can be constructed in free space
  - for covert sensing in detail, imaging and materials investigation

Basic Science

- We seek to understand fs pulses leading to filamentation and resultant plasmas
- fs induced filamentation with external EM field interactions and resultant plasmas are excellent basic science medium to attempt to answer the fundamental questions posed above

USPL Technologies Research:

- DoD via HEL-JTO is rethinking USPL investment strategy, DDR& expending $15M, "Femtosecond (fs) filamentation as leading candidate to localize electromagnetic (EM) fields"
  - Sensing, imaging, and non-imperceptible communications (e.g. hypersonic UAVs)

- AFRL/RD Based Defense S&T Strategy for Mid-Term 2017-2022
  - Low collateral damage, non-lethal

- Capabilities Sought:
  - DoD USPL Investment Strategy
  - Interaction of USPL induced filaments with High E-Fields
  - Covert sensing in detail, imaging and materials investigation
  - New USPL mathematical and computational models

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We are not interested in!

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Nor This!

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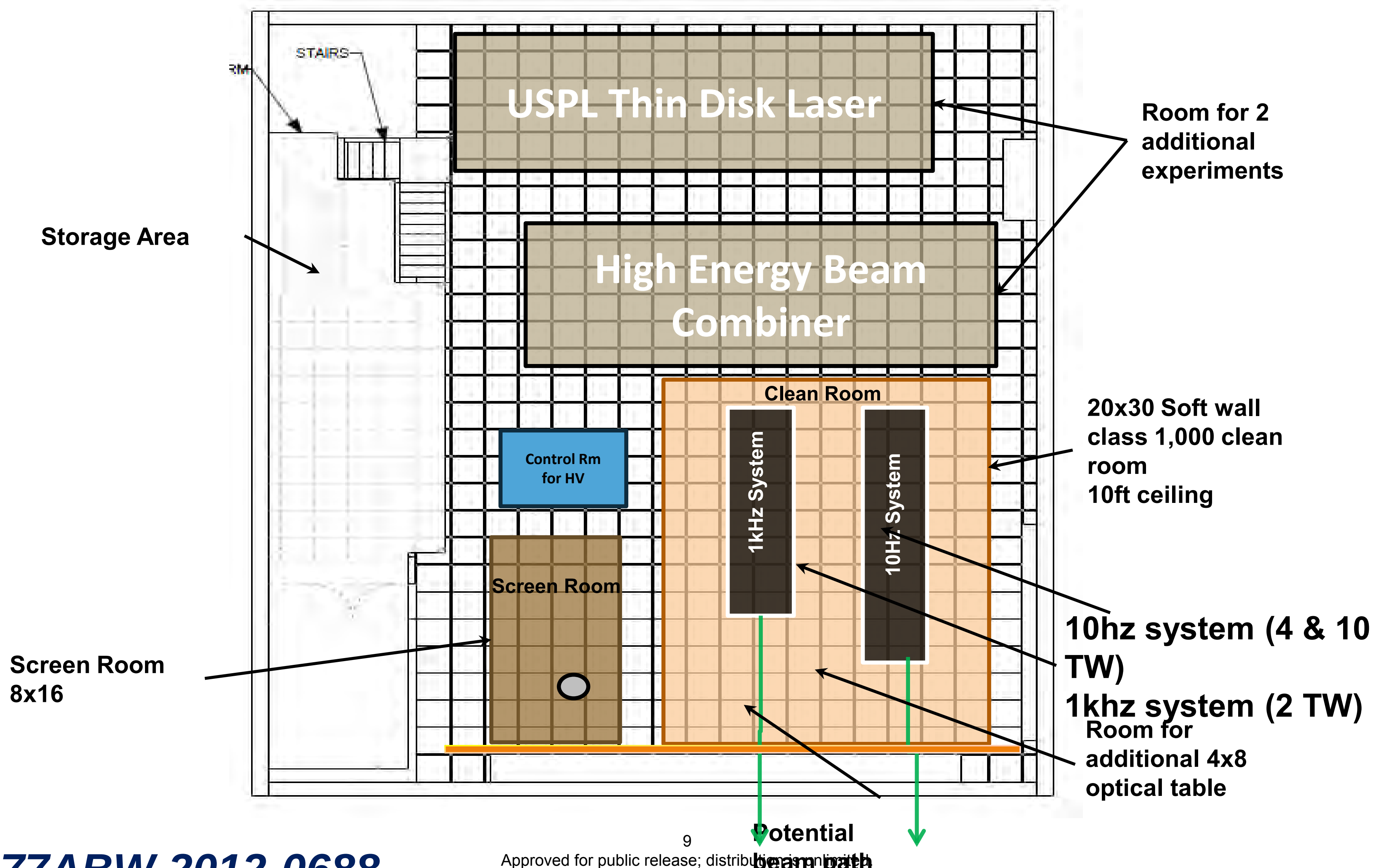
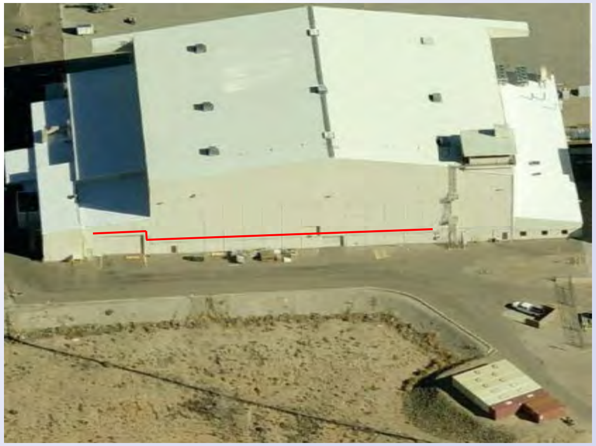
Ultra Short Laser Lab Layout Plan



Our Building History in 2010

- Turn on Pump Lasers from Bldg. 243
- Demolition lab
- Addition Electrical Supply



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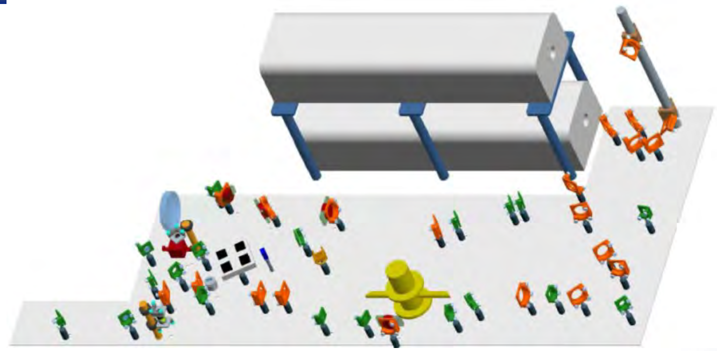
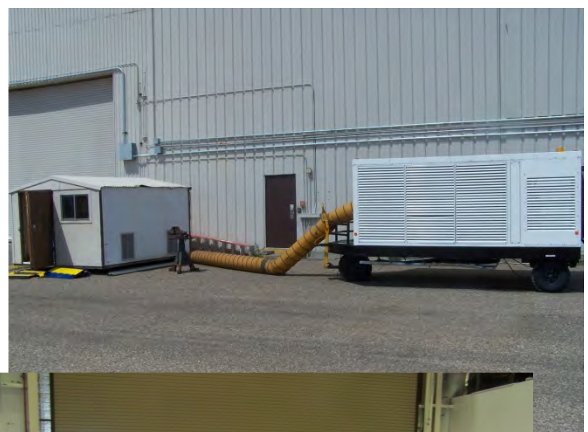
Original Drawings New Paint and a Raised Floor

- Move Temporary shed of water chiller
- Temporary Cooling
- Drawings to transfer optics
- Paint
- Raised Floor





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11

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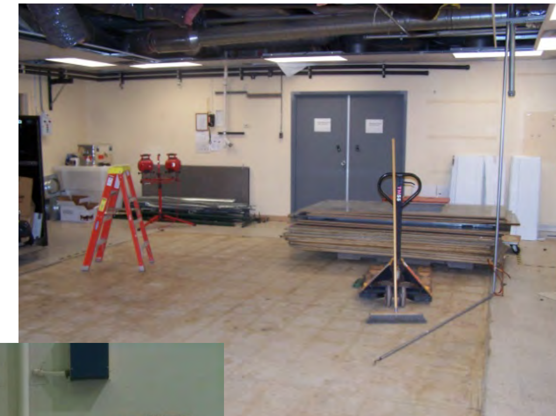
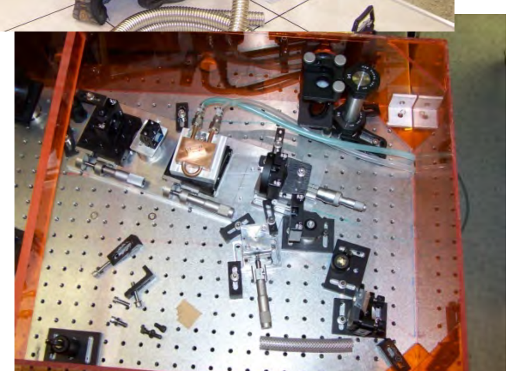
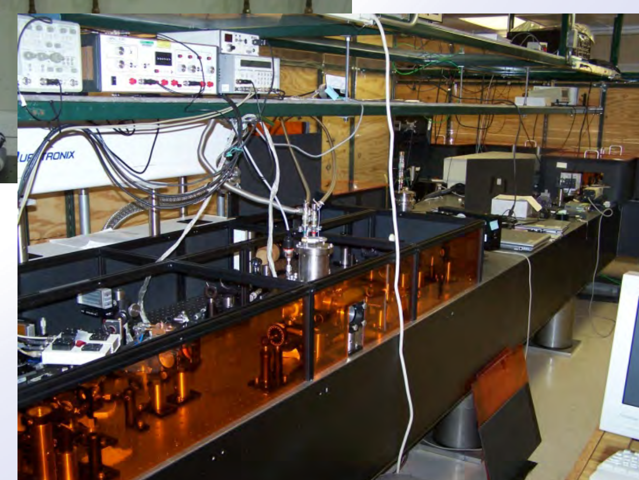
Electrical/Plumbing/Optics

- **Additional Power 2-Electrical Panels**
- **Water Manifolds**
- **Transfer Optics to Breadboards**
- **Disassemble Screen**







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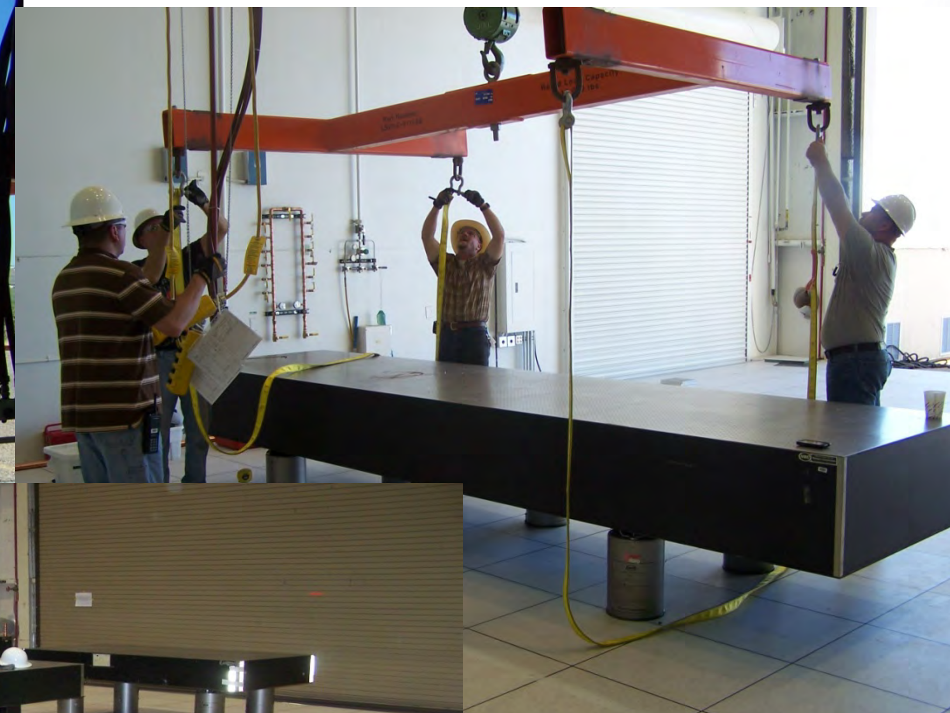
Moving Day June 2010

- Move 20ft & 16ft Optical tables
- Optics/Lasers
- Equipment

Brining It All In!

- Place 6 optical tables in lab



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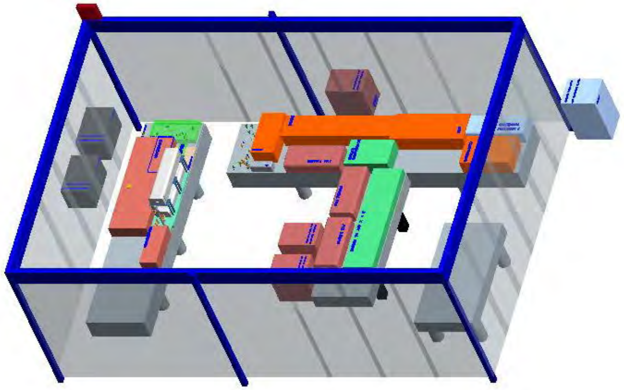
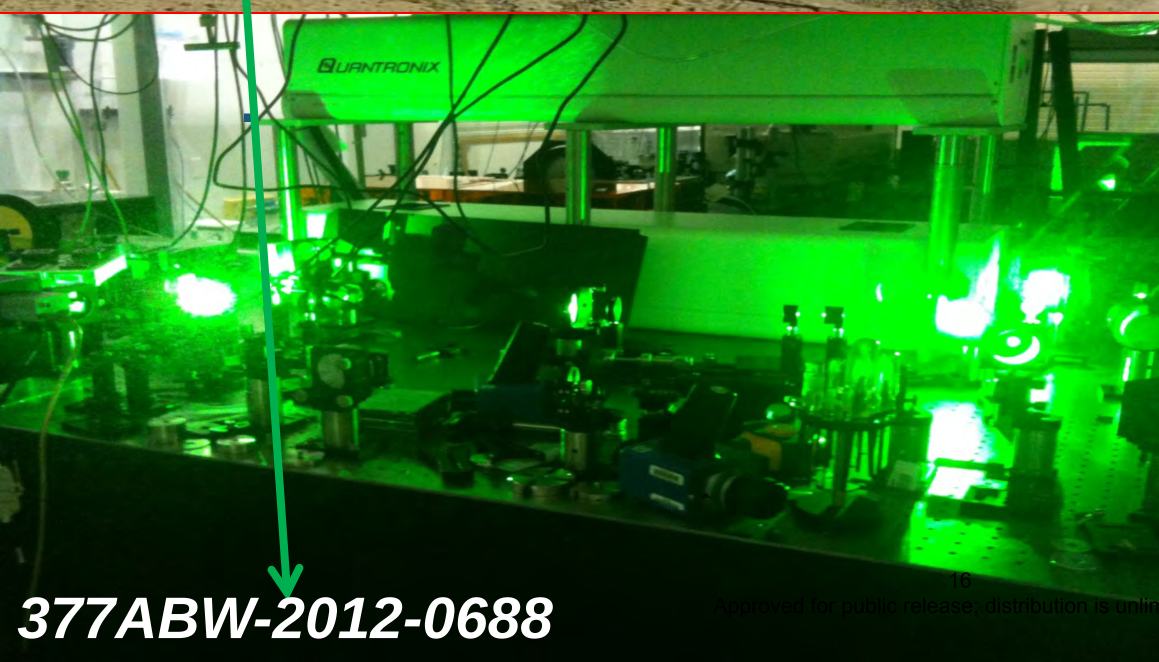
Original Placement

- Optical tables in Lab & floating (3)
- Water manifolds
- Lab automation
- Clean room being built
- Work in Process



AFRL/RDLA
RANGE: 2k and 5k pre-designated ranges



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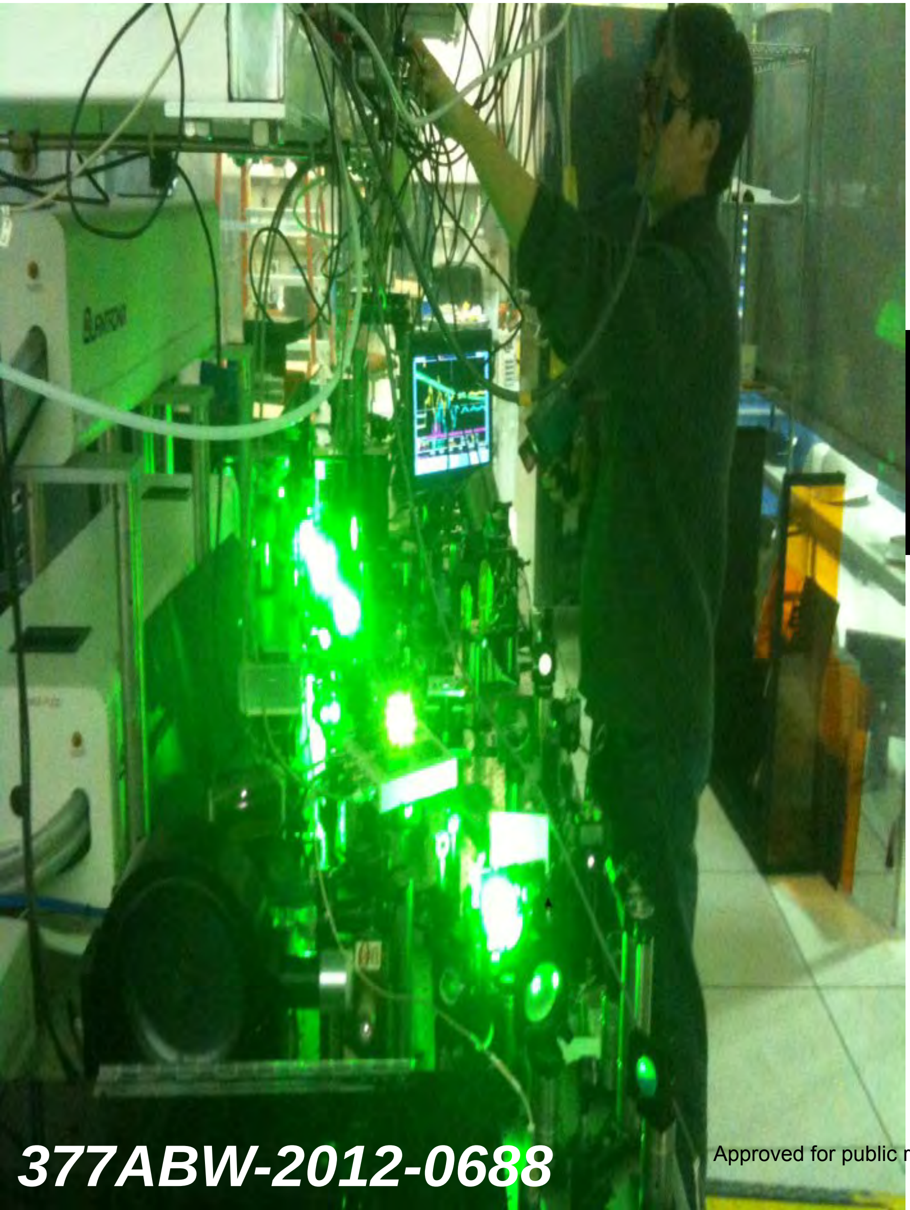
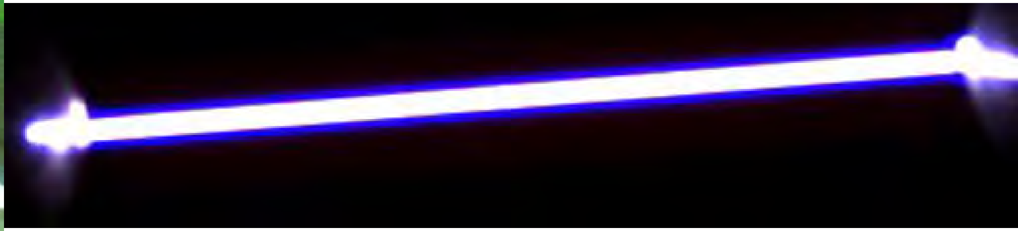
Krispy Kreme Dream Team

- The USPL Lab was only possible due to the following Team

AFRL/RDLA USPL Filamentation Team Update



60 fs at 800 nm
20 – 400 mJ, ~ 6.5 TW Max
sustained, continuous filament bundles (15-20 filaments at 250 mJ)
measured out to 10m



9-inch filament bundle propagation through kV-level E-Field

Studying the interaction of electric fields (RF, AC and Optical) with the filament

USPL Group: Dr. Erik Bochove, Dr. W.P. Latham, Professor M.R. Zunoubi, Dr. Andreas Schmitt-Sody, Mr. Adrian Lucero, Mr. Chunte Lu, and Mr. N. Wolfe

377ABW-2012-0688

USPL Technologies Research: In Support of DoD DDR&E MURI

Research Objectives	Areas of Discovery
Write HEL/JTO USPL strategic investment strategy	Military Utility of USPL Wednesday 13 June 2012 Afternoon, **Ultrashort Laser Physics, Novel Material Interactions and Measurements** 2:05-2:30 FOUO-C
Demonstrate filamentation shorting in high voltage transformers for counter electronics	Effect may trigger circuit fault leading to electrical grid shut down. Wednesday 13 June 2012 Afternoon **Ultrashort Laser Physics, Novel Material Interactions and Measurements** 2:30-2:55 FOUO-C
Characterize fs-laser filament physics necessary for coupling/confining external EM-Fields	Microwave and RF guiding with a single filament Wednesday 13 June 2012 Afternoon **Ultrashort Laser Physics, Novel Material Interactions and Measurements** 2:30-2:55 FOUO-C
Develop computational models for fs propagation as an extended free space waveguide	New mathematical & computational models within in the framework of specific observed USPL phenomenon and V&V Thursday 14 June 2012 Morning , **Non-Linear Propagation Physics** , 8:10-8:35 & 8:35-9:00

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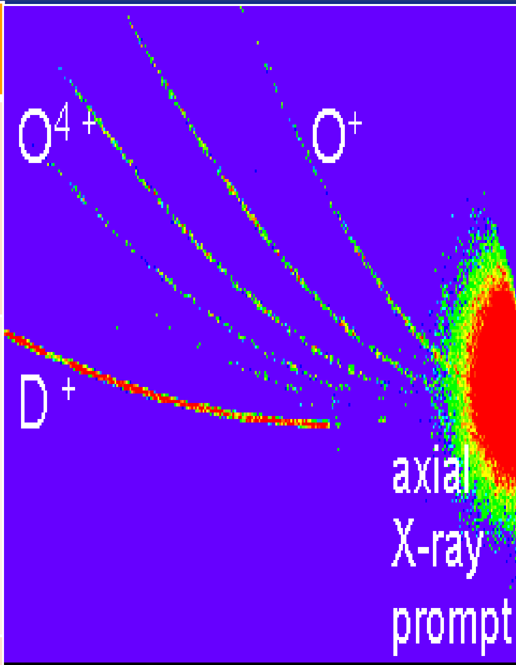

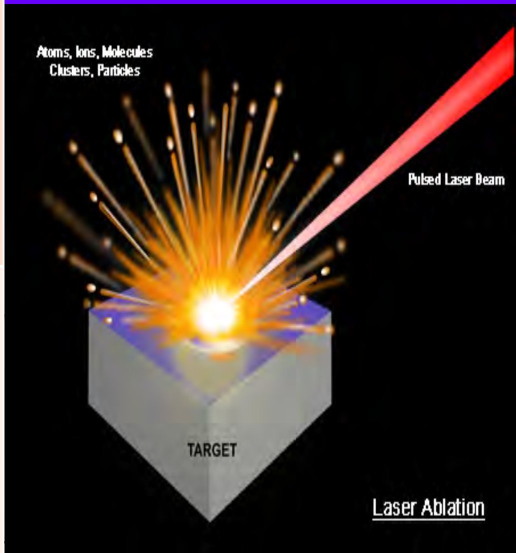

Why Do We Care?

Iraq Diary: Jammers Beat Bombers (Which May Be Bad News) Read More
http://www.wired.com/dangerroom/2007/09/iraq-diary-jamm/#ixzz0qvWArigQ

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Navy: More Bomb-Blasting Ray Guns, Please

http://www.wired.com/dangerroom/2010/06/militarys-mystery-ray-gun-to-zap-bombs-change-the-face-of-this-war/#ixzz0qvVH5T8z

377ABW-2012-0688

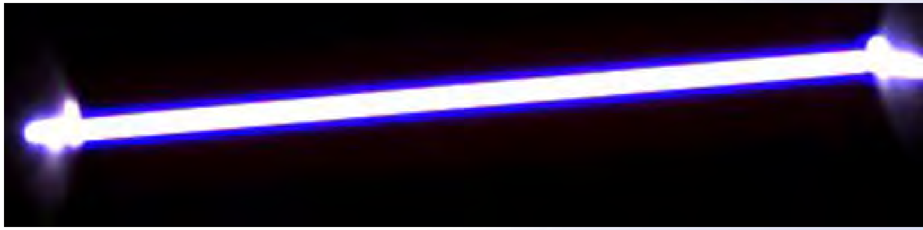
AFRL/RDLA_RHDO USPL Filamentation Team

60 fs at 800 nm

60 – 140 mJ, ~ 2.1 TW Max

sustained, continuous filament bundles (8-10 filaments at 140 mJ)

measured out to 4m



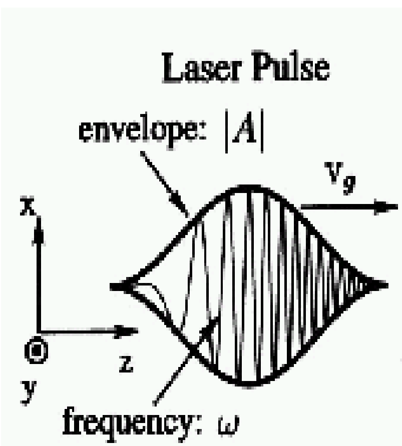
9-inch filament bundle propagation through kV-level E-Field

Measuring the filament interaction with a very high E-Field allows us to begin to describe the physics of the filaments

Filamentation Characterization

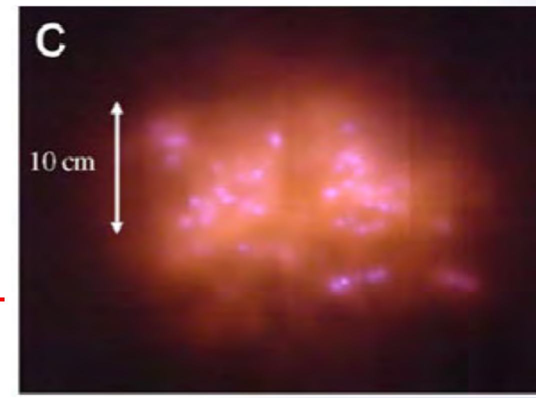
Dr. Andreas Schmitt-Sody NRC Fellow

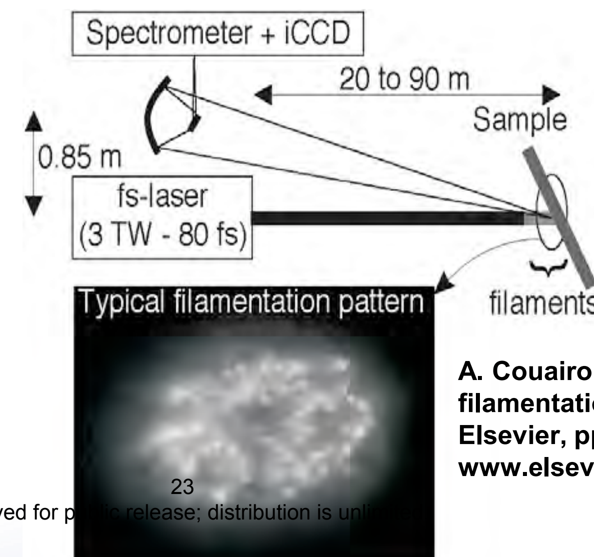
- High power, femtosecond laser beams propagating through air form extremely long filaments due to nonlinear self-focusing ($\chi^{(3)}$) dynamically balanced by ionization and defocusing.



$$n_{eff} = n_0 + \underbrace{\delta n_{gas} + \delta n_{plasma}}_{\approx 0}$$

$$P_{cr} \sim \lambda^2/8n_0n_2$$



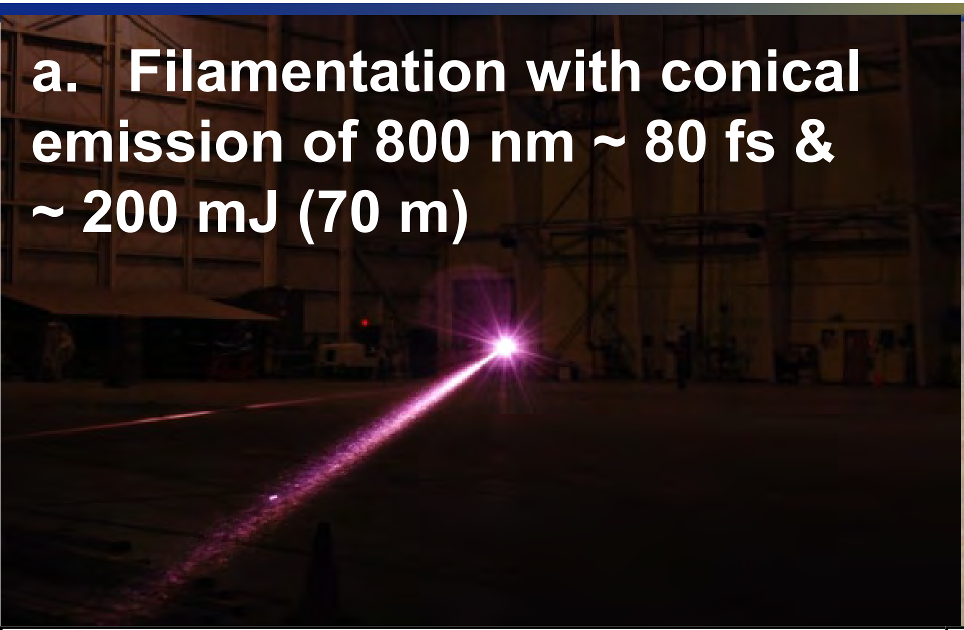


S. Varma, Y.-H. Chen, and H. M. Milchberg
Institute for Research *in Electronics and Applied Physics*
Dept. of Electrical and Computer Engineering
Dept. of Physics

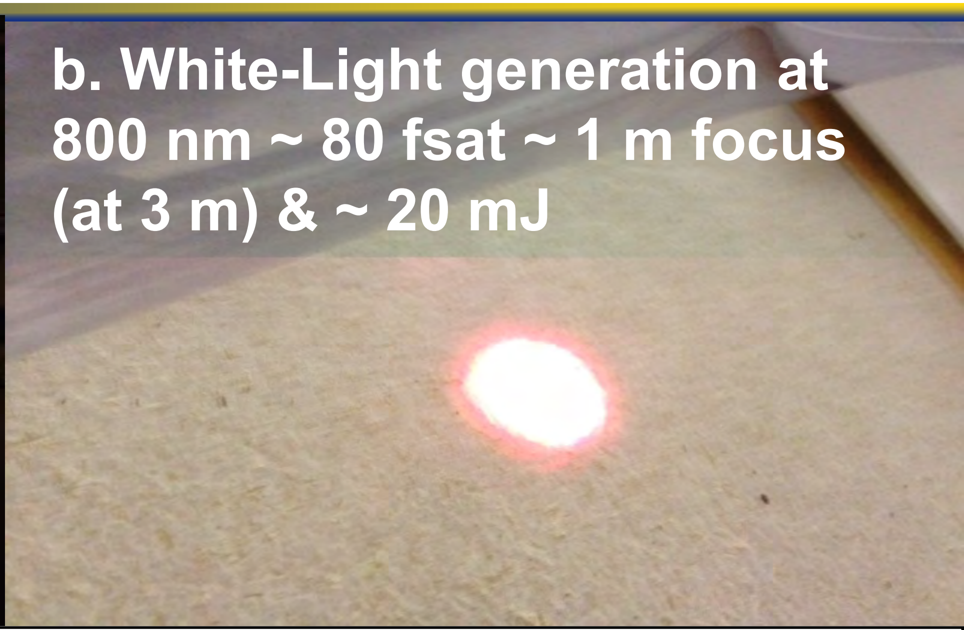
A. Couairon *and A. Mysyrowicz,* Femtosecond filamentation in transparent media, Physics Reports, Elsevier, pp 47 – 189, 441 (2007) www.elsevier.com/locate/physrep

Propagation Into The Hangar
~80fs at 800 nm and 100 mJ

Propagation Into The Hangar



a. Filamentation with conical emission of 800 nm ~ 80 fs & ~ 200 mJ (70 m)



b. White-Light generation at 800 nm ~ 80 fsat ~ 1 m focus (at 3 m) & ~ 20 mJ

Heater-Igniter Experiments

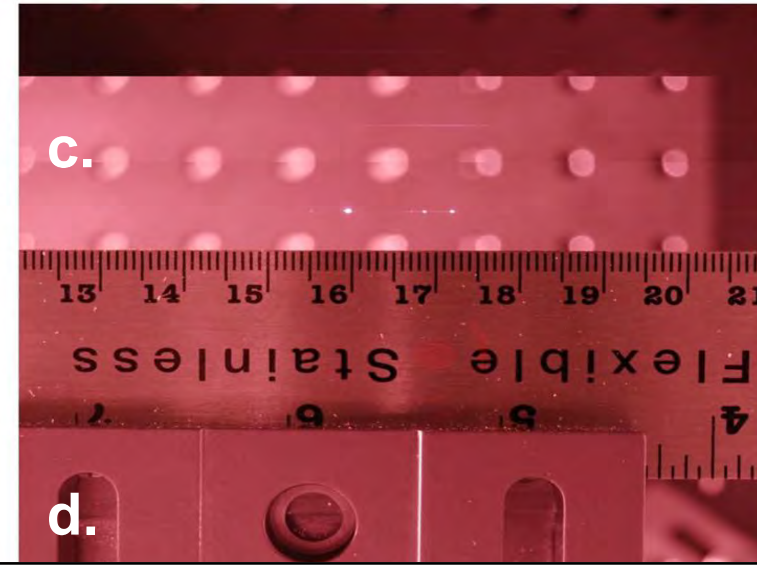
MURI AFRL/UA Collaborative Experiments

1. Purpose is to extend the life time and the number of ions within the filament.
2. Igniter pulse was 400 nm at ~ 100 fs and ~1-2 mJ
3. The delay between the igniter and the heater pulses was between 100 – 500 ps
4.

Igniter: Faint plasma

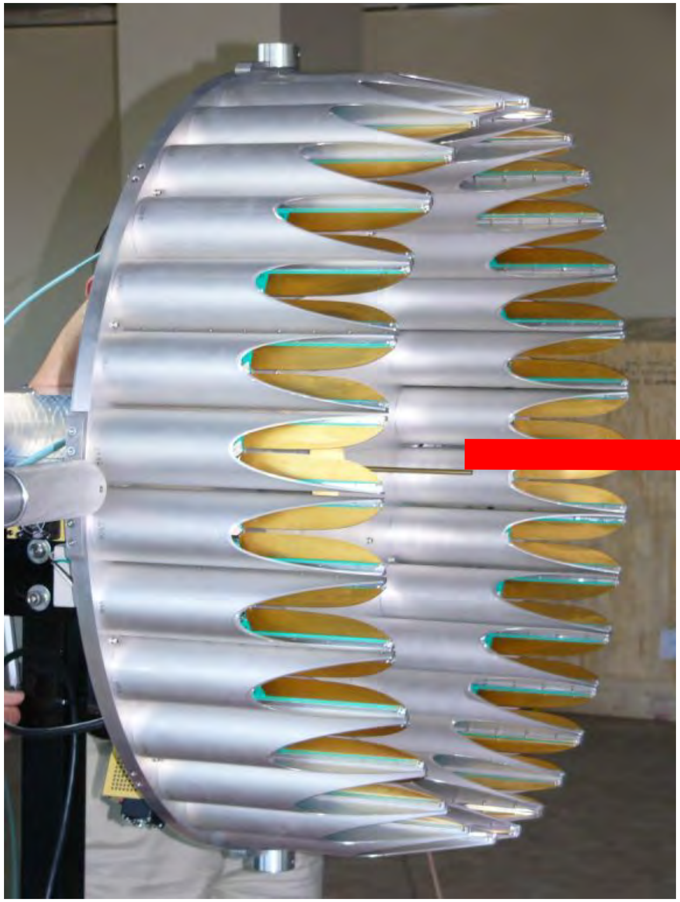
Igniter +heater: increase in brightness, e.g. more plasma

Heater: avalanche breakdown and bubbles.



Work In the late 90's

Fields and Plasma Filaments



Fire laser through center

of circular array

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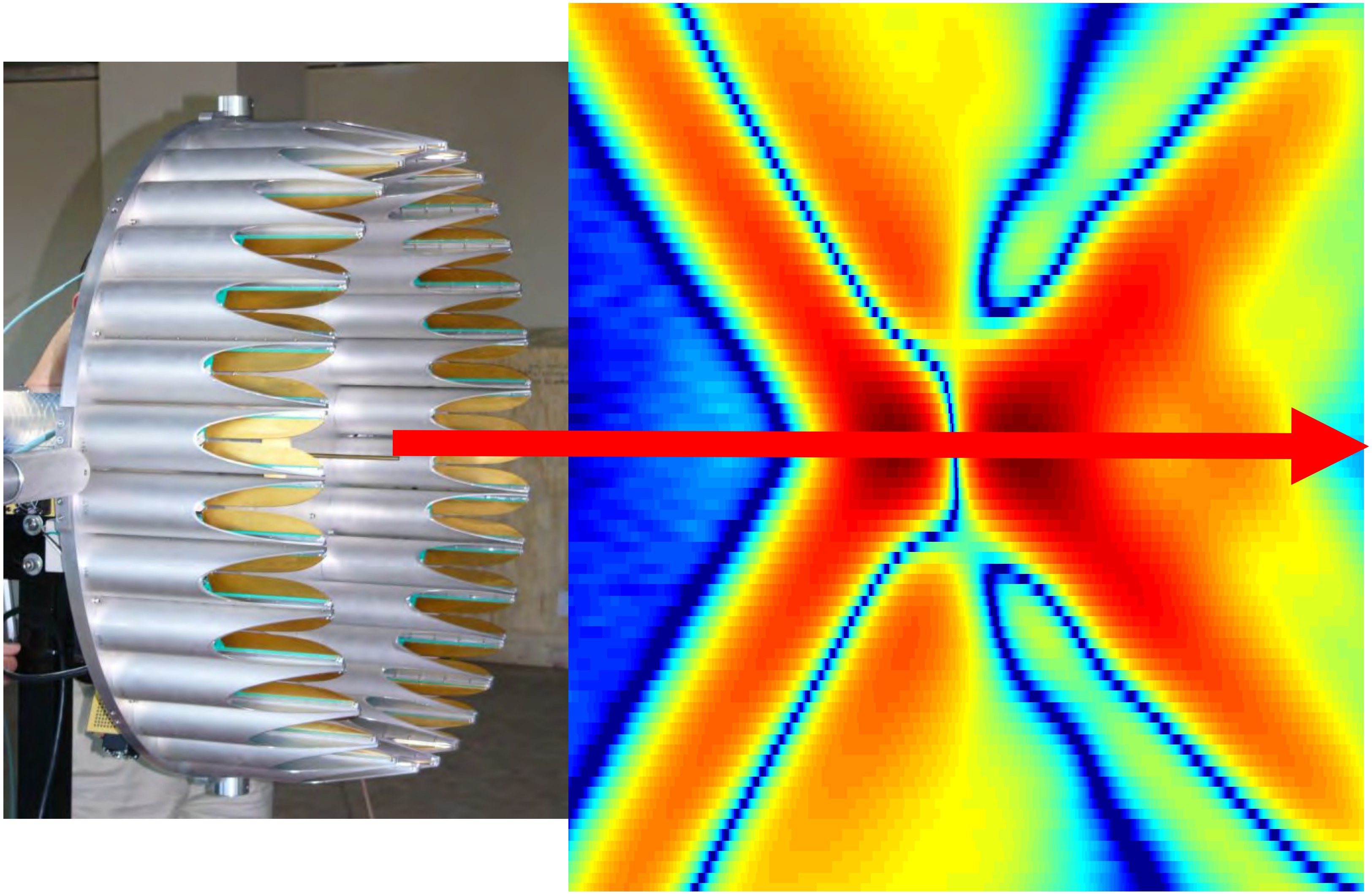
Fields and Plasma Filaments



Summary and Conclusions

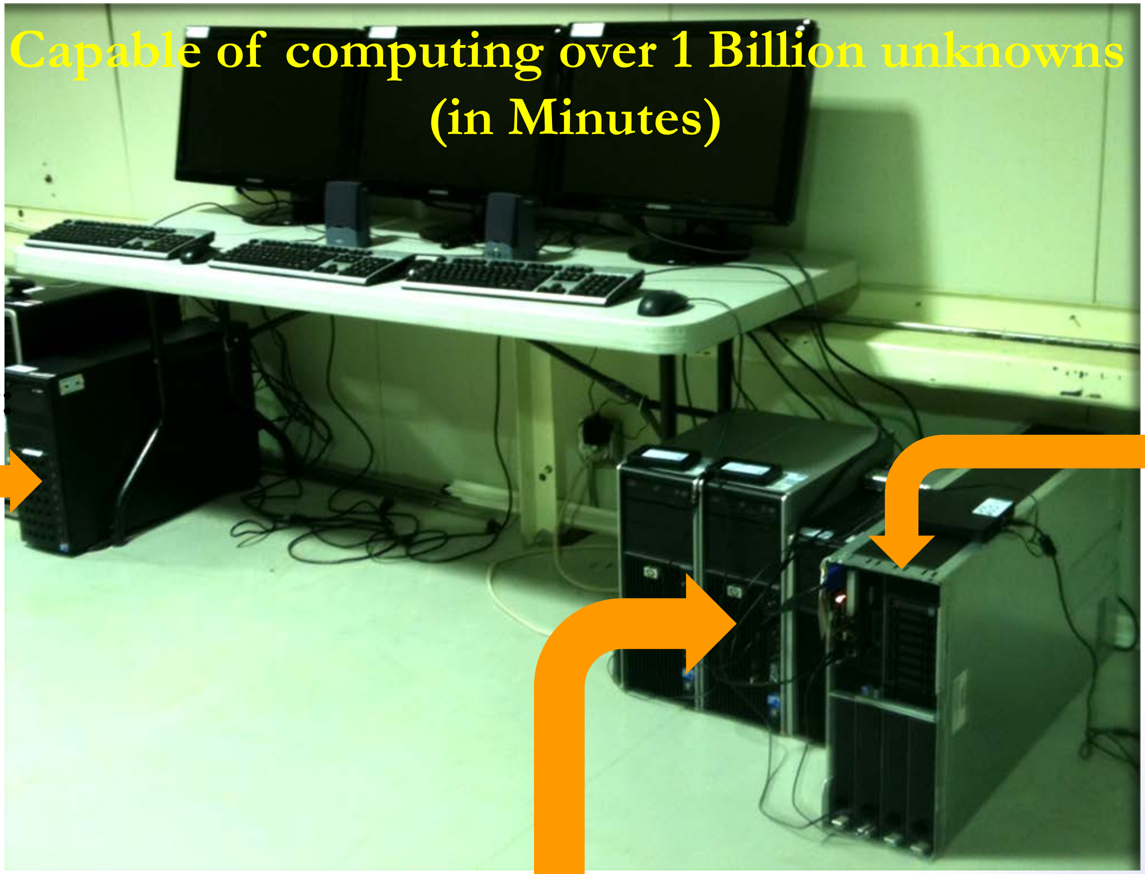
- USPL Laboratory Update
  - Reconfigured and now achieving 6.5 TW
  - Propagate laser to 2k & 5k site has begun
- Progress on Nonlinear Propagation
  - Media with second and third harmonic generation present mathematical complexities in previous results that have been now simplified
- Work on competing nonlinearities and propagation
  - We have deviated from Farnum/Kutz work to include a more uniform definition for dispersion
  - We have kept the 2^{nd} order derivatives in time for a finer look at dispersion.
  - Under SEVA and other assumptions our equations reduce to a form previously published but little computational work on them is available
- Computational efforts underway
  - New results from a RK5 & FFT methodology and 6-pt Crank-Nicholson for our simplest form
  - We will move to solve the more complicated forms numerically in the future
  - Couple this work with plasma work by our group

QUESTIONS?


Ultrashort Pulse Laser Lab
AIR FORCE RESEARCH LABORATORY
The New Mexico State Bird
We may be short, but at least we're quick

BACK UP SLIDES

High-Performance GPU Computing Enclave



24-Core CPU Supercomputer:

- 18 GBs of dedicated memory
- Over 3 Teraflops/s floating point performance

Tesla Compute Machine:

- 48 GBs of dedicated memory
- Over 9 Teraflops/s floating point performance

Basic HP Desktops (×3):

- 18 GBs of dedicated memory
- Over 3 Teraflops/s floating point performance

A Numerical Approach to Solving Our Equations

- **By introducing a coordinate system which moves with an average group velocity,** $v_g^{'} = \dfrac{2}{k_1^{'} + k_2^{'}}$ **, in equations (I.) and (II.) where:**

$$\xi = \varepsilon z, \quad \tau = \left(t - z/v_g^{'}\right), \quad \delta = \frac{1}{2}\left(k_1^{'} - k_2^{'}\right)$$

- **These equations may be cast into a compact form:**

$$i\partial_\tau U + i\delta\partial_\xi U + i\Gamma_1 U + fU^* V e^{-iR\delta\xi} + \left[a|U|^2 + b|V|^2\right]U = 0$$

$$i\partial_\tau V + i\delta\partial_\xi V + i\Gamma_2 V + gV^2 e^{iR\delta\xi} + \left[c|V|^2 + d|U|^2\right]V = 0$$

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A Numerical Approach to Solving Our Equations

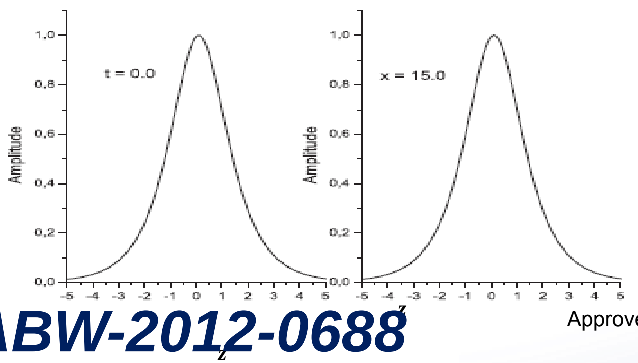
- **Using a new 6-point unconditionally stable FD –TD scheme, we write:**

$$i\frac{U_i^{j+1}-U_i^j}{\tau}+i\delta\frac{U_{i+1}^{j+1}+U_{i+1}^{j}-U_{i-1}^{j+1}-U_{i-1}^{j}}{4h}+i\Gamma_1\frac{U_i^{j+1}+U_i^j}{2}+f\frac{U^{*j+1}_i+U^{*j}_i}{2}\frac{V_i^{j+1}+V_i^j}{2}e^{-iR\xi_i^j}+\left(a|U_i^{j+1/2}|^2+b|V_i^{j+1/2}|^2\frac{U_i^{j+1}+U_i^j}{2}\right)=0$$

$$i\frac{V_i^{j+1}-V_i^j}{\tau}-i\delta\frac{V_{i+1}^{j+1}+V_{i+1}^{j}-V_{i-1}^{j+1}-V_{i-1}^{j}}{4h}+i\Gamma_2\frac{V_i^{j+1}+V_i^j}{2}+g\left(\frac{U_i^{j+1}+U_i^j}{2}\right)^2e^{iR\xi_i^j}+\left(c|V_i^{j+1/2}|^2+d|U_i^{j+1/2}|^2\frac{V_i^{j+1}+V_i^j}{2}\right)=0$$

- **Some early results for coupled NLSE applied to multi-mode optic fibers using a Matlab implementation (Note: a dispersion term was added in the form of ∂_{zz})**

Soliton Solution (includes dispersion and nonlinearity



Effect of dispersion on Gaussian pulse (includes dispersion term only)